Journal Club

Editor's Note: These short reviews of recent *JNeurosci* articles, written exclusively by students or postdoctoral fellows, summarize the important findings of the paper and provide additional insight and commentary. If the authors of the highlighted article have written a response to the Journal Club, the response can be found by viewing the Journal Club at www.jneurosci.org. For more information on the format, review process, and purpose of Journal Club articles, please see http://jneurosci.org/content/preparing-manuscript#journalclub.

Age-Related Changes in Frontal, Striatal, and Medial Temporal Activity during Expected Value Evaluation

Carina Fernandes[1,2,3]

[1]Laboratory of Neuropsychophysiology, Faculty of Psychology and Education Sciences and [2]Faculty of Medicine, University of Porto, 4200-135 Porto, Portugal, and [3]Language Research Laboratory, Institute of Molecular Medicine, Faculty of Medicine, University of Lisbon, 1600-276 Lisboa, Portugal

Review of Goh et al.

A growing number of studies have indicated that aging alters decision-making processes, but the knowledge about the trajectory and causes of these changes are still limited (Samanez-Larkin and Knutson, 2015). A recent meta-analysis revealed that age-related differences in decision-making vary as function of context (Mata et al., 2011). In experiments requiring decisions under uncertainty, in which probabilities and possible outcomes must be learned through feedback from previous choices, older adults were more risk-seeking than younger adults when learning should have made them risk-averse, but were more prone to risk-aversion when learning should lead to risk-seeking. However, in experiments requiring decisions under risk, in which probabilities and outcomes are fully known, younger and older adults showed similar decision-making behavior (Mata et al., 2011). Studies using the Iowa Gambling Task (Bechara et al., 1994) have indicated that individual differences may also influence the effect of aging on decision-making. For instance, in a study by Denburg et al. (2005), although older adults overall had worse performance than younger adults, a subset of older participants as well as younger adults performed the Iowa Gambling Task. Moreover, differences between older adults' performance was not explained by age, education level, or neurocognitive function. Nevertheless, the influence of individual differences on decision-making is considerably less studied than the influence of context.

In a recent publication, Goh et al. (2016) used fMRI to identify neural correlates of value processing associated with individual differences in decision-making throughout aging. To achieve this, the authors assessed cognitively healthy older adults with a lottery choice task. Each trial was divided into a choice phase and a feedback phase. In the choice phase, participants were offered a stake (a number of points that they would win or lose), along with the probability of winning or losing the stake. The participants had to decide whether to accept or reject the stake, based on the amount and the probability of winning or losing, which determined the expected value (EV). In the feedback phase, participants viewed the outcome of each trial and the total accumulated points.

Functional imaging revealed several regions of the frontal, striatal, and medial temporal areas that were sensitive to EV variation, regardless of age or individual risk preferences. Specifically, activity in the right inferior frontal gyrus, left caudate, ventral ACC, and mPFC increased with increasing EVs, whereas activity in the putamen, thalamus, right middle frontal gyrus, left inferior frontal gyrus, and hippocampus increased with decreasing EVs.

In addition, Goh et al. (2016) found that risk preferences vary substantially within older adults, consistent with evidence from Iowa Gambling Task studies (Denburg et al., 2005). Based on the pattern of decisions, the authors divided their sample into three subsamples: risk-neutral older adults who declined trails that had EVs $= 0$; risk-takers who accepted stakes with EVs < 0; and risk-averters who declined stakes with EVs > 0. This variability in risk preferences was associated with group differences in frontal, striatal, and medial-temporal responses to EVs during choice evaluation. Specifically, compared with participants neutral to risk, risk-averters had greater activation of the anterior cingulate region, medial superior frontal gyrus, bilateral parahippocampal gyri, right orbitofrontal gyrus and caudate, and left thalamus and putamen, to increasing EVs. In contrast, risk-takers had greater neural responses to decreasing EVs, consistent with a propensity for experiencing gains under risk. Interestingly, risk-takers also showed more striatal activation to gains than losses, which was

Received Jan. 5, 2017; revised Feb. 26, 2017; accepted Feb. 28, 2017.

This work was supported by Fundação BIAL Grant and Fundação para a Ciência e Tecnologia Doctoral Fellowship SFRH/BD/112101/2015 to C.F.

The author declares no competing financial interests.

Correspondence should be addressed to Carina Fernandes, Laboratório de Neuropsicofisiologia, Faculdade de Psicologia e de Ciências da Educação, University of Porto, R. Alfredo Allen, 4200-135 Porto, Portugal. E-mail: carinafernandes@fpce.up.pt.

DOI:10.1523/JNEUROSCI.0033-17.2017

 0270-6474/17/373442-03$15.00/0

interpreted as a possible indication of greater surprise (Goh et al., 2016).

The important role of frontal, striatal, and medial temporal areas in the anticipation of gains and losses and in value integration had previously been highlighted in the affect-integration-motivation framework (AIM), which attempts to clarify how affective and motivational circuits support decision-making in aging (Samanez-Larkin and Knutson, 2015). The AIM proposes that three sequential processes precede choice. First, affect processes potentiate anticipation of gains and losses; these processes are associated with mesolimbic dopamine projections to NAc and other areas, noradrenaline projections from locus ceruleus to anterior insula, and glutamatergic projections from anterior insula to ventral striatum. Second, integration processes facilitate the integration of values of each choice with other relevant inputs; these processes are associated with ventral tegmental area dopamine neurons and locus ceruleus noradrenaline neurons, both of which project to mPFC and back to ventral striatum. Finally, motivational processes potentiate motor action; they are associated with dorsal striatal and insular glutamatergic neurons that project to the presupplementary motor area. Aging may be associated with degeneration of glutamatergic projections from mPFC to the striatum, which could diminish value integration and compromise optimal choices (Samanez-Larkin and Knutson, 2015). This may explain why Goh et al. (2016) found a positive association between increasing age and risky decisions, despite increasing frontal responses to costlier choices.

Results from previous studies suggest that the differences in risk preferences among older adults found by Goh et al. (2016) may be explained by differences in emotional and motivational processes. Aging appears to preserve gain anticipation, associated with NAc activity, but reduces loss anticipation, associated with anterior insula activity. This could lead to overvaluation of anticipated rewards. Moreover, older adults show reduced reward learning, which may be related to diminished NAc responsiveness to violated reward expectations, as well as degraded connectivity from mPFC to NAc (Samanez-Larkin and Knutson, 2015). Moreover, if gain anticipation circuits are preserved while value integration circuits are degraded, dynamic updating and probabilistic learning might be compromised, in agreement with the assumptions of the AIM (Samanez-Larkin and Knutson, 2015). This hypothesis is also supported by the results of Goh et al. (2016), which evidenced that risk-takers accepted risks when losses were likely, even after receiving negative feedback. This difficulty of changing the decision strategy after negative feedback also accords with the positivity effect (Mather et al., 2012), which postulates that older adults allocate more attention to and are better able to memorize positive emotional materials than negative stimuli (Nashiro et al., 2012).

The positivity effect (Mather et al., 2012) is understudied in contexts of economic decision. The positivity effect can be harmful because affective responses that anticipate disadvantageous outcomes may fail. For instance, if older adults allocate more attention to positive materials, they may neglect the negative aspects of a choice, or minimize negative consequences of an outcome. This hypothesis is supported by a previous study, which showed that older adults, compared with younger adults, had decreased activity in the right insula (whose activity is related to risk avoidance) (Paulus et al., 2003), during loss, but not gain, anticipation (Samanez-Larkin et al., 2007). Furthermore, in tasks involving decisions under uncertainty, older adults needed more trials than younger adults to learn the association between stimuli and rewards (Mell et al., 2009), and aging was associated with a weaker and less extensive striatal activation during the processing of outcomes (Cox et al., 2008; Mell et al., 2009).

The results found with risk-averters are more difficult to explain because they are less consistent with previous findings. According to Goh et al. (2016), the risk-averters made disadvantageous choices by not accepting risks when gains were likely. Despite it being widely hypothesized that older adults may be worse decision-makers because of increased risk-aversion (Deakin et al., 2004), several studies showed that older adults' preference for safer choices appears to be task-dependent (Lee et al., 2008; Zamarian et al., 2008; Henninger et al., 2010; Hosseini et al., 2010). For instance, one study revealed that older adults were simultaneously more risk-averse and risk-seeking: they preferred a sure gain over a chance to win a higher reward but chose to take a chance on losing a large reward rather than accepting a sure smaller loss. (Mather et al., 2012). This result is in accordance with the prospect theory, which postulates that individuals are risk-averse for gains (preferring to choose smaller certain outcomes than larger uncertain outcomes) and risk-seeking for losses (preferring to choose a larger possible loss than a smaller certain loss) (Kahneman and Tversky, 1979). This pattern of preferences is called the certainty effect and appears not to change with age. The findings of Goh et al. (2016) with the risk-averse subsample may be best explained by the changes in activity in ventral striatum and the ACC. Both of these areas are involved in making risky decisions and in successful reward-based learning (Marschner et al., 2005; Huettel et al., 2006; Schultz, 2006) and were not found to be activated during anticipation of gains (Dreher et al., 2008).

In conclusion, the findings of Goh et al. (2016) advance our understanding of the mechanisms underlying decision-making during aging. Their results highlight the key role of the frontal, striatal, and medial temporal areas in making value-based decisions, in accordance with the AIM framework (Samanez-Larkin and Knutson, 2015). Furthermore, they reinforce evidence that, within the elderly, decision-making strategies are heterogeneous, and individual differences must be further studied to allow the identification of individual vulnerabilities to making disadvantageous decisions. In addition, further studies must investigate the underlying mechanisms of loss aversion because it is a less consistent finding in decision-making throughout aging.

References

Bechara A, Damasio AR, Damasio H, Anderson SW (1994) Insensitivity to future consequences following damage to human prefrontal cortex. Cognition 50:7–15. CrossRef Medline

Cox KM, Aizenstein HJ, Fiez JA (2008) Striatal outcome processing in healthy aging. Cogn Affect Behav Neurosci 8:304–317. CrossRef Medline

Deakin J, Aitken M, Robbins T, Sahakian BJ (2004) Risk taking during decision-making in normal volunteers changes with age. J Int Neuropsychol Soc 10:590–598. CrossRef Medline

Denburg NL, Tranel D, Bechara A (2005) The ability to decide advantageously declines prematurely in some normal older persons. Neuropsychology 43:1099–1106. CrossRef Medline

Dreher JC, Meyer-Lindenberg A, Kohn P, Berman KF (2008) Age-related changes in midbrain dopaminergic regulation of the human reward system. Proc Natl Acad Sci U S A 105: 15106–15111. CrossRef Medline

Goh JO, Su YS, Tang YJ, McCarrey AC, Tereshchenko A, Elkins W, Resnick SM (2016) Frontal, striatal, and medial temporal sensitivity to value distinguishes risk-taking from risk-aversive older adults during decision making. J Neurosci 36:12498–12509. CrossRef Medline

Henninger DE, Madden DJ, Huettel SA (2010) Processing speed and memory mediate age-related differences in decision making. Psychol Aging 25:262–270. CrossRef Medline

Hosseini SM, Rostami M, Yomogida Y, Takahashi M, Tsukiura T, Kawashima R (2010) Aging and decision making under uncertainty: behavioral and neural evidence for the preservation of decision making in the absence of learning in old age. Neuroimage 52:1514–1520. CrossRef Medline

Huettel SA, Stowe CJ, Gordon EM, Warner BT, Platt ML (2006) Neural signatures of economic preferences for risk and ambiguity. Neuron 49:765–775. CrossRef Medline

Kahneman D, Tversky A (1979) Prospect theory: an analysis of decision under risk. J Econ Soc 47:263–291.

Lee TM, Leung AW, Fox PT, Gao JH, Chan CC (2008) Age-related differences in neural activities during risk taking as revealed by functional MRI. Soc Cogn Affect Neurosci 3:7–15. CrossRef Medline

Marschner A, Mell T, Wartenburger I, Villringer A, Reischies FM, Heekeren HR (2005) Reward-based decision-making and aging. Brain Res Bull 67:382–390. CrossRef Medline

Mata R, Josef AK, Samanez-Larkin GR, Hertwig R (2011) Age differences in risky choice: a meta-analysis. Ann N Y Acad Sci 1235:18–29. CrossRef Medline

Mather M, Mazar N, Gorlick MA, Lighthall NR, Burgeno J, Schoeke A, Ariely D (2012) Risk preferences and aging: the "certainty effect" in older adults' decision making. Psychol Aging 27:801–816. CrossRef Medline

Mell T, Wartenburger I, Marschner A, Villringer A, Reischies FM, Heekeren HR (2009) Altered function of ventral striatum during reward-based decision making in old age. Front Hum Neurosci 3:1–10. CrossRef Medline

Nashiro K, Sakaki M, Mather M (2012) Age differences in brain activity during emotion processing: Reflections of age-related decline or increased emotion regulation? Gerontology 58:156–163. CrossRef

Paulus MP, Rogalsky C, Simmons A, Feinstein JS, Stein MB (2003) Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism. Neuroimage 19:1439–1448. CrossRef Medline

Samanez-Larkin GR, Knutson B (2015) Decision making in the ageing brain: changes in affective and motivational circuits. Nat Rev Neurosci 16:278–289. CrossRef Medline

Samanez-Larkin GR, Gibbs SE, Khanna K, Nielsen L, Carstensen LL, Knutson B (2007) Anticipation of monetary gain but not loss in healthy older adults. Nat Neurosci 10:787–791. CrossRef Medline

Schultz W (2006) Behavioral theories and the neurophysiology of reward. Annu Rev Psychol 57:87–115. CrossRef Medline

Zamarian L, Sinz H, Bonatti E, Gamboz N, Delazer M (2008) Normal aging affects decisions under ambiguity, but not decisions under risk. Neuropsychology 22:645–657. CrossRef Medline